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PHOTOGRAPHIC EQUIPMENT
TEST SYSTEM (PETS)

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FINAL REPORT

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Itek

OPTICAL SYSTEMS DIVISION

1450 PAGE MILL ROAD
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1.0 INTRODUCTION

The Photographic Equipment Test System (PETS) is a mobile optical system designed for evaluating performance of various sensors in a laboratory, in a vacuum chamber or on a flight line. The carriage is designed to allow elevation as well as azimuth control of the direction of the light from the collimator. The pneumatic tires provide an effective vibration isolation system. A target/illumination system is mounted on a motor driven linear slide, and focusing and exposure control can be operated remotely from the small electronics control console.

1.1 DESCRIPTION OF SYSTEM

The overall system (Figure 1-1) is approximately 3.5 feet wide by 8.5 feet long by 52 inches high and weighs about 2,000 pounds. The support structure consists of a welded steel frame mounted on four pneumatic wheels. The optical system is supported by a 3.5 ft x 8 ft x 8 inch thick honeycomb table which in turn is supported by a welded steel "bed frame." The bed frame is supported at the front end by three pillow block bearings and at the rear by a heavy duty jack screw. Operation of the jack screw allows the optical axis of the system to be depressed by 5° or elevated by 2°. The honeycomb table has 3/16-inch thick stainless steel plates on top and bottom. A matrix of 1/4-20 tapped holes on 1-inch centers covers the top of the table. These serve to attach the various components to the table, as well as provide some venting for vacuum operation. Three solid cores have been inserted into the table. These cores have been drilled and tapped to accept eye bolts for removal of the table from the bed frame. Three clamps under the table, located at the solid cores, anchor the table to the bed frame.

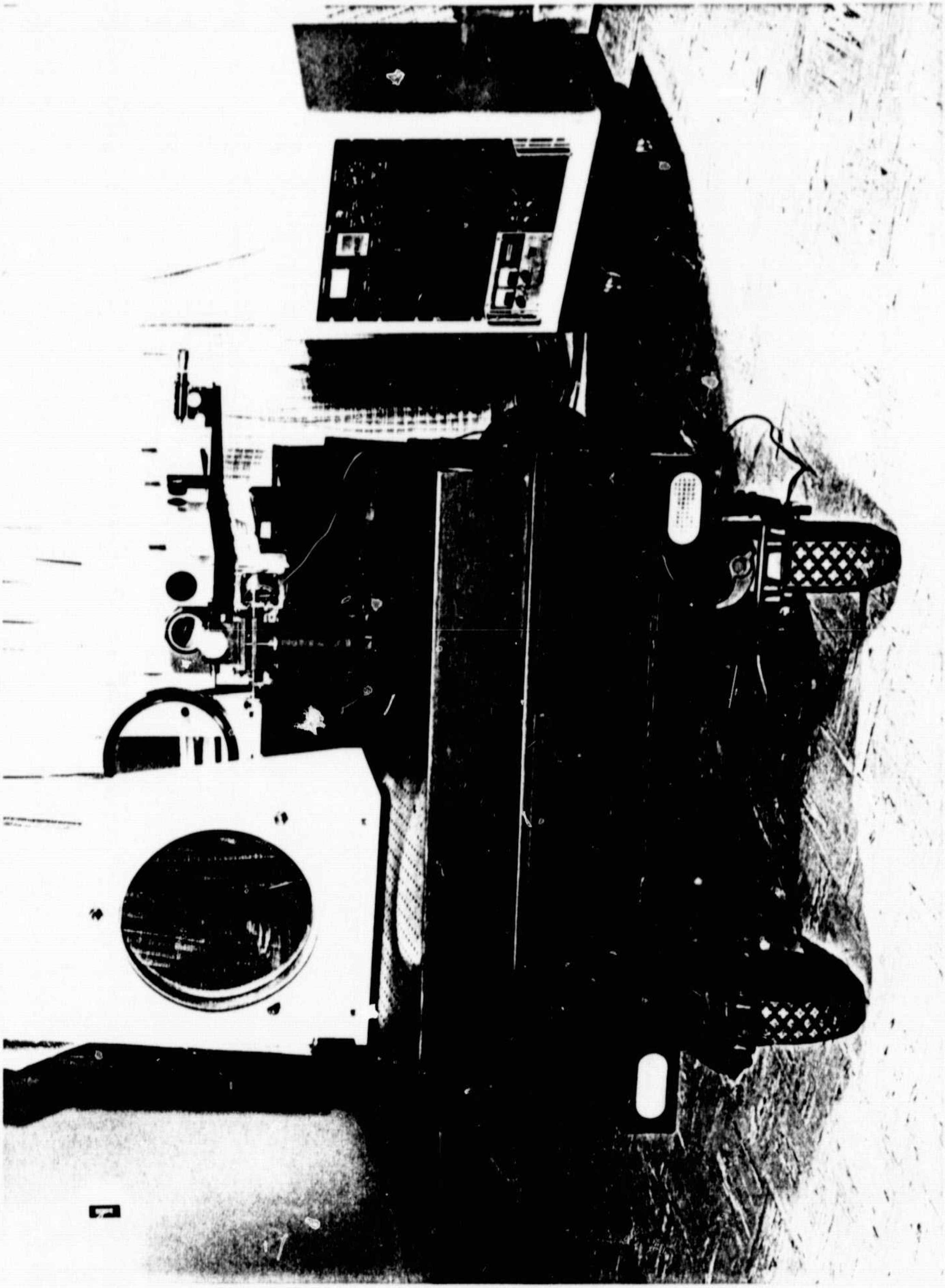

FIGURE 1-1 PETS

The collimator consists of a 120-inch focal length f/10 on-axis parabola/beamsplitter combination with a focusable target/illumination system with spectral and brightness control. A shutter, capable of remote operation, is provided with exposure times up to 1/200 second. A strobe flash lamp can be inserted to evaluate forward motion compensation (FMC) of various systems. Strobe operation is controlled from a small electronics package mounted on the table between the parabola and the light source. The electronics junction box is also used to provide power to the entire system through a cable from the control console.

1.2 ELECTRONICS CONTROL CONSOLE

The electronics control console (Figure 1-2) consists of a small roll-around cabinet in which are located the lamp and focus drive power supplies, the illumination monitor meter, the focus control switches and counter, and the shutter control. A door at the back and lid on top of the console provide easy access to the various components. The 120 volt, 60 Hz power cable is connected through the back, under the door, as is the molded cable which supplies power to the table, through the junction box on the table. Circuit breakers in the lower right panel serve as on-off switches for console power and table power and provide protection for both units.

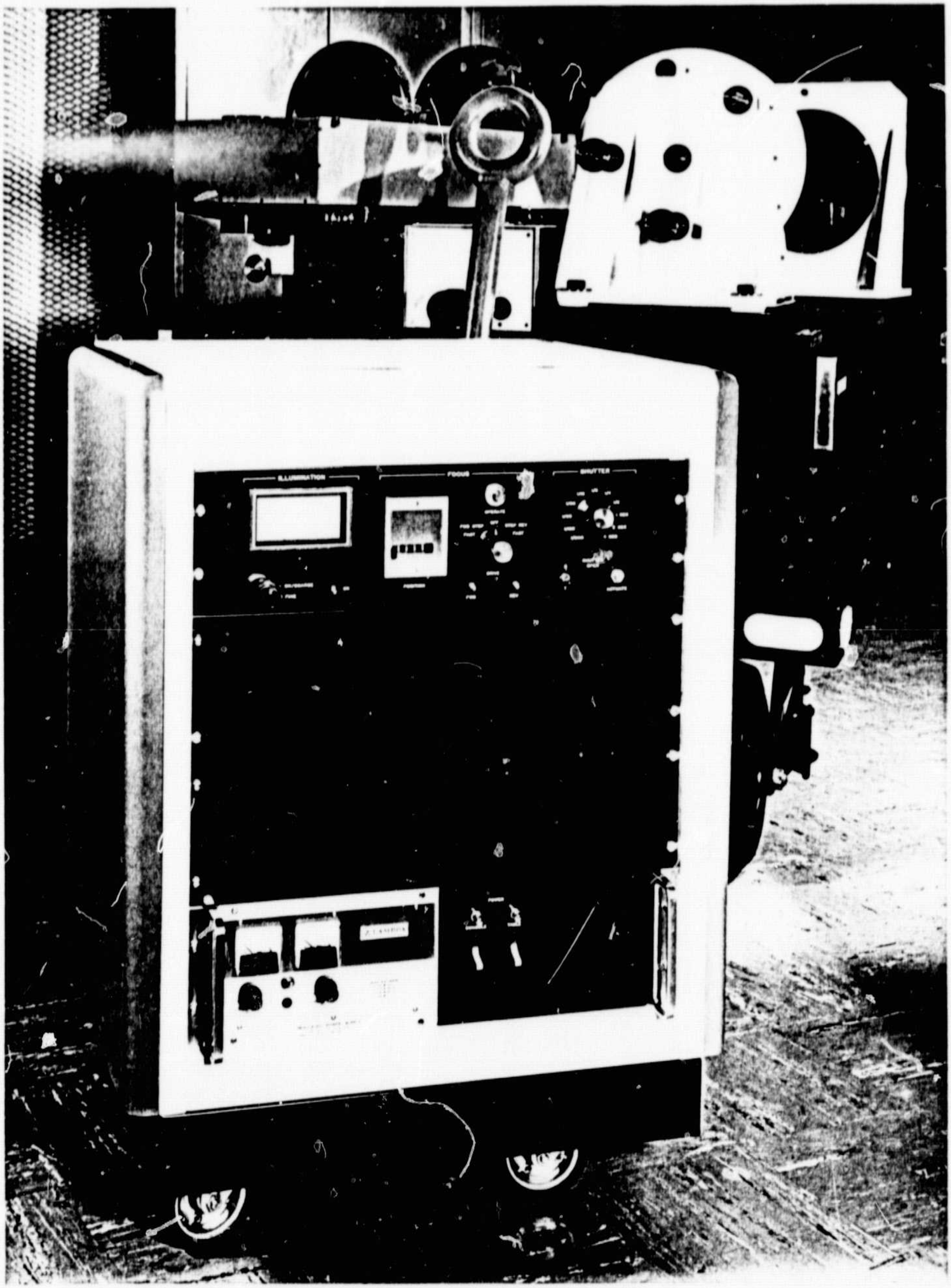

FIGURE 1-2 CONTROL CONSOLE

2.0 THEORY OF OPERATION

2.1 COLLIMATOR

The collimator, a 120-inch focal length f/10 on-axis parabola/beamsplitter combination, has been designed to provide excellent optical performance over a wide range of environmental conditions. The parabola (Figure 2-1) is a 12-inch diameter, 2-inch thick Cervit substrate for thermal stability, aluminized and overcoated with an enhanced broadband reflective coating. It is potted in a modified Unertl mount using GE RTV-11 silicone rubber. The mount has been stiffened to reduce its susceptibility to vibration.

The beamsplitter, approximately 13.5 inches in diameter and 2 inches thick, is made of schlieren grade fused silica. It has an Inconel coating on the reflective side and a MgF_2 anti-reflection coating on the back side. The Inconel coating, while absorbing approximately 1/3 of the incident light and therefore is not very efficient, is quite neutral spectrally which is a requirement for FETS. Like the parabola, the beamsplitter is also potted with RTV-11 in a ring. This ring is supported by three studs which are designed to provide necessary tip and tilt adjustments for alignment.

Since the collimator is an all reflective system, it is completely achromatized and is independent of atmospheric pressure conditions which might otherwise affect focus in a refractive system. The two faces of the beamsplitter are sufficiently plane parallel to make chromatic dispersion due to prism effects negligible.

2.2 TARGET/ILLUMINATION SYSTEM

The target/illumination system, as shown in Figure 2-2

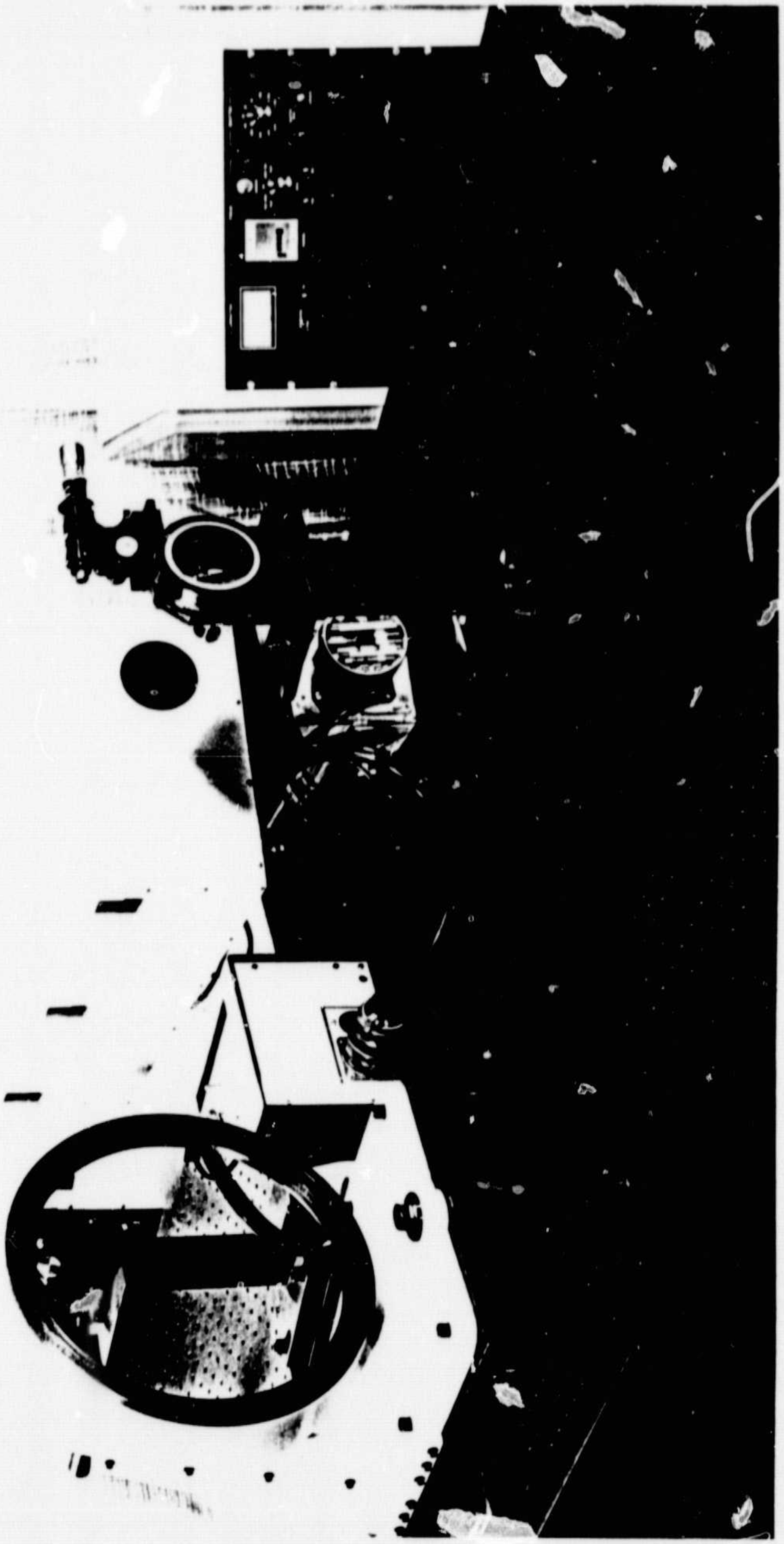

FIGURE 2-1 PARABOLA

FIGURE 2-2 TARGET ILLUMINATION SYSTEM

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contains the light source and condenser system, shutter, illumination detector, spectral and neutral density filter wheels, test targets and strobe for FMC testing. The entire system is mounted on a motor driven focusing stage, and an autocollimation system for setting infinity focus is provided.

2.2.1 Illumination System

A 21.5 volt, 250 watt DKP motion picture projection lamp is used as the light source. An aperture, behind which are placed two 0.12-inch thick opal glass diffusers, is located at the same place a film gate would normally go in a projector. The lamp life, nominally about 25 hours, is extended somewhat by the console circuit design. If the lamp has been operating until the main power had been shutoff, it is necessary to turn the lamp potentiometers to the OFF position before it will come back ON. This procedure prevents the life-shortening current surge which otherwise might occur if full power were suddenly applied to the lamp.

The lamp and socket undergo significantly elevated temperatures, particulary when operating in a vacuum or near-vacuum. No fan is used with the system and convection is adequate in air. When used in vacuum, lamp operation should be limited to about 5-minute periods, although laboratory tests have shown that it will still operate over at least 30 minutes. The shutter and other elements could possibly be damaged with excessive lamp operation. Because of the elevated temperatures encountered, the socket has been modified to replace the normal spring clips which retain the lamp base pins with two brass tubes and set screws, without solder connections. This makes changing of lamps a little less convenient, but ensures better reliability under the elevated temperature conditions.

A two element condenser system projects an enlarged image of the diffuse aperture onto the target, behind which a field lens is located to ensure uniformity of illumination across the two inch target aperture.

2.2.2 Targets

A series of 20 targets of various types are provided, including resolution, vertical and horizontal line and star targets, as well as an edge target and an autocollimation target. All these targets are on glass discs, with the exception of the autocollimation target which is on film in a special holder. All the targets are mounted in a wheel which can be indexed into any desired position. There is one blank hole, approximately 7/8 inch in diameter in which a special target (e.g., pinhole) may be mounted. A 2-inch diameter hole (blank) is also provided for special targets. A mask behind the targets is used for the smaller targets, and prevents unwanted adjacent targets from being illuminated. The mask may be removed to illuminate the 2-inch aperture.

The outside face of the target wheel is registered against a roller for accurate focus setting, while ball-pins on the back side are indexed by a nylon-plastic spring loaded detent plunger Numerals on the edge of the target wheel identify the target in use. The number can be seen just above the side wall of the unit with the cover off, or just below the lower edge of the cover door assembly with the cover on and door open.

The targets are identified as follows:

0.	2 inch aperture (blank)			
1.	Autocollimation			
2.	USAF 1951	1000:1 contrast		1 c/mm to 228 c/mm
3.	USAF 1951	6:1 contrast		1 c/mm to 228 c/mm
4.	USAF 1951	1.6:1 contrast		1 c/mm to 228 c/mm
5.	Vertical line		0.001"	
6.	Vertical line		0.003"	
7.	Vertical line		0.01"	
8.	Vertical line		0.03"	
9.	Vertical line		0.10"	
10.	Horizontal line		0.001"	
11.	Horizontal line		0.003"	
12.	Horizontal line		0.01"	
13.	Horizontal line		0.03"	
14.	Horizontal line		0.10"	
15.	Star		0.001"	
16.	Star		0.003"	
17.	Star		0.01"	
18.	Star		0.03"	
19.	Star		0.10"	
20.	Blank			
21.	Edge target			

All line and star targets have line lengths of 0.5 inches. The star targets each consist of four intersecting lines.

2.2.3 Autocollimation

An autocollimation fixture, consisting of a relay lens and microscope mounted on a pin-located arm attached to the side of the light source assembly, is used to establish infinity focus of the collimator. A small beamsplitter can be swung into the light beam by turning the handle which extends out the side of the light box. The beamsplitter is registered against a magnet by an adjustable screw which gives azimuth adjustment. A spring loaded screw provides elevation control.

Because the illumination level of the autocollimated image is relatively low in double pass through the collimator, it is advisable to remove the field lens which reflects sufficient light to reduce contrast severely. The autocollimation target has a hole to one side of the target through which hole the return image is projected. This procedure also improves contrast since there are no reflecting surfaces in this region.

Autocollimation is achieved by setting a plane mirror outside the collimator and aligning it to reflect the target back through the adjacent hole. Focus of the stage is adjusted (either from the console or manually) until the return image lies in the same plane as the original image. The film target is sufficiently thin to cause a negligible error when sighting the microscope through the film on one side and through an open hole on the other.

2.2.4 Filters

Two wheels contain filters; the one closer to the lamp has seven neutral density filters in 0.15 density increments, plus one open hole. The second wheel has a set of seven different color filters and one open hole. The neutral density filters are Inconel

deposited on glass discs 0.06" thick. The color filters are 0.004" thick gelatin Wratten series filters sandwiched between two 0.03" thick glass discs. All the filters are held in place with nylon screws and washers.

In similar fashion to the target wheel, the filter position is read by numbers on the edge which can be seen by looking down past the edge of the door frame when the cover door is open.

The filters, as read in this manner, are identified as follows:

Neutral Density Filters		Color Filters	
Number	Density	Number	Color
1	0.15	1	W-2A
2	0.30	2	W-12
3	0.45	3	W-15
4	0.60	4	W-25
5	0.75	5	W-47B
6	0.90	6	W-57
7	1.05	7	W-89B
8	blank (0)	8	blank

2.2.5 Shutter

An electronically controlled remotely operated shutter is located near the aperture/diffuser assembly. The shutter blades are stainless steel, with the side toward the lamp shiny to reduce the thermal load. The opposite side of the blades is coated with black Teflon. Shutter speeds, controlled at the console, range from "bulb" or "time" settings to as fast as 1/200 second. A small light on the console indicates shutter opening.

2.2.6 Illumination Control

A thin uncoated glass plate reflects a small percentage of the illuminating beam to an encapsulated photodetector. The detector actually is a duo-diode arrangement, one of which is blind. The electronics are designed through this technique to be quite insensitive to thermal changes. When the two filter wheels are set to the open positions, the light meter on the console should then read full scale. Zero and gain adjustments are made with small screwdriver slots on the back of the module. A 0.6 neutral density filter is cemented in the module to attenuate the light to bring the light level into the linear range of the detector.

2.2.7 Forward Motion Compensation (FMC) Test

A strobe lamp extension head, consisting of a xenon lamp and reflector assembly, is located on a rotatable arm behind the target assembly. When not in use, the strobe unit is swung out of the way and retained by a clip. For FMC operation, the arm is lowered against a registration pin to place the lamp directly behind a target on the optical axis. Strobe frequency is controlled by setting in the proper rate on the dial of the control unit located in the junction box between the parabola and light source. (Figure 2-3)

2.2.8 Focus Drive

The entire light source assembly is mounted on a slide which is driven through a lead screw by a stepping motor. Normally, one pulse of the 200 step per revolution motor would give an 0.0005 inch increment. However, the electronics are arranged to double pulse the motor to give 0.001 inch increments and a one digit increment on the console counter. The counter can be zeroed for the autocollimated or infinity setting and reads in increasing value for

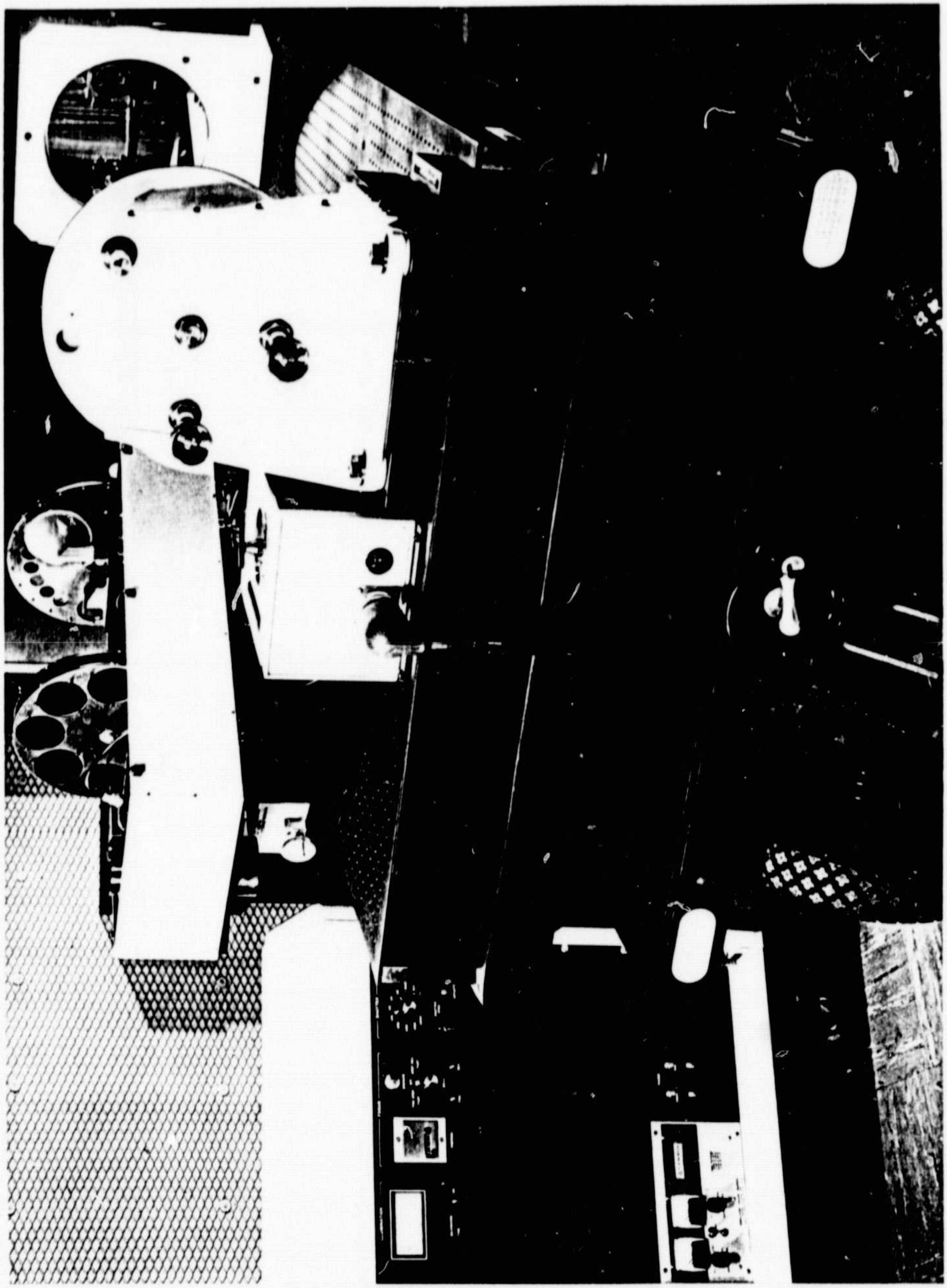

FIGURE 2-3 JUNCTION BOX

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forward motion and decreasing for reverse direction. The drive may be singly stepped or fast stepped in either direction. For manual operation of the drive, the motor cable should be disconnected.

2.3 OPTICAL AXIS VISUALIZER

As an aid in aligning PETS to sensors under test, a laser and mirror assembly have been designed to project the laser beam out through the collimator centered on the optical axis. Both the laser and the mirror assembly have tip/tilt adjustments to align the beam. The mirror pedestal is placed between the beamsplitter and target/illumination system, on axis, and is registered with two pins to ensure easy removal and accurate replacement.

2.4 WAVEFRONT VERIFIER

The same mirror used for the optical axis visualizer may be rotated so that the optical axis is rotated approximately 90° and an interferometer may be placed in the folded focal plane to measure the optical wavefront quality of the collimator when an auxiliary autocollimating flat is used. The rotational axis, determined by a shoulder screw, passes through the front face of the mirror, a 3-inch diameter $\lambda/20$ aluminized flat. A retractable pin is used to register the mirror in either one of two positions.

APPENDIX A

TARGET SPECIFICATION AND COLLIMATOR FOCUS RATIO

PETS (8284) TARGET SPECIFICATIONS

Target Disc Size:

0.875" + 0.005" Dia.
Nominally 0.06" thick glass photographic plate.

A. BAR TARGETS

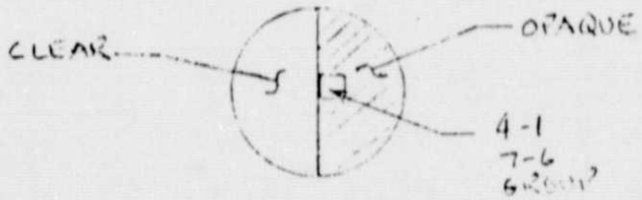
Standard USAF 1951 configuration, groups 0-1 thru 7-6 (1 c/mm thru 228 c/mm). Clear bars, dark background.

Contrast ratio:

1. 1000:1
2. 6:1
3. 1.6:1

B. AUTOCOLLIMATION TARGET

Target groups 4-1 thru 7-6. High contrast (1000:1) with clear bars on opaque background. Target to be placed off center of disc, but adjacent to center. Second half of disc to be clear.

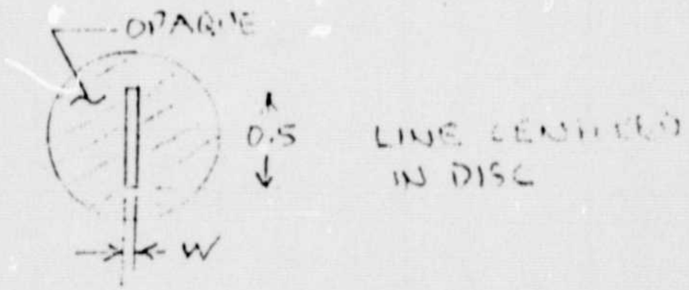


C. LINE TARGETS

Single clear line 0.5" $^{+0.02''}_{-0}$ long in opaque (D=3.0) background.

Line widths (W):

1. 0.001" ± 0.0001"
2. 0.003" ± 0.0003"
3. 0.01" ± 0.001"
4. 0.03 ± 0.002"
5. 0.10" ± 0.005"

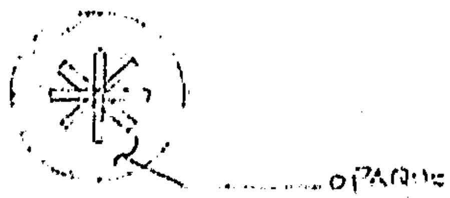


D. **STAR TARGETS**

Four intersecting clear lines. Each line $0.5^{+0.02}_{-0}$" long in opaque (D=3.0) background. Angles between lines nominally 45°. Line widths to be same as line targets.

Line Widths (W):

1. 0.001" ± 0.0001"
2. 0.003" ± 0.0003"
3. 0.01" ± 0.001"
4. 0.03" ± 0.002"
5. 0.10" ± 0.005"



CAMERA FOCAL LENGTH	REDUCTION RATIO (R) $f_{COLL.} / f_{CAMERA}$	FOCUS RATIO (R^2)	RESOLUTION RANGE (C/mm) 0-1 (1 C/mm)	7-6 (228 C/mm)
48"	2.5 :1	6.25:1	2.5	570
36"	3.33:1	11.11:1	3.33	760
24"	5 :1	25:1	5	1140
18"	6.67:1	44.45:1	6.67	1520
12"	10:1	100:1	10	2280
6"	20:1	400:1	20	4560
3"	40:1	1600:1	40	9120

APPENDIX B

SYSTEM ANALYSIS REPORT

PHOTOGRAPHIC EQUIPMENT TEST SYSTEM (PETS)
SYSTEM ANALYSIS REPORT
18 APRIL 1975

1.0 INTRODUCTION

Operational environmental conditions of atmospheric pressure and temperature can have an effect on the performance of PETS. These parameters are the subject of this System Analysis Report.

2.0 TECHNICAL DISCUSSION

2.1 Atmospheric Pressure Effects

PETS is designed to operate over a fairly broad range of environmental conditions, from a laboratory to a flight line to a high altitude chamber. The resulting pressure variation can range from one atmosphere to 1.0 psi. The reduced pressure changes the index of refraction of the air so that a refractive collimator would undergo a focus shift. However, PETS has an all-reflective collimator consisting of a beam-

splitter and parabolic mirror and therefore will suffer no change in focus due to changes in pressure and the resulting changes in index of refraction.

In the event of explosive recompression of the chamber, no damage would be anticipated to any of the optical components or mounts. It is possible that the honeycomb structure in the table might suffer some damage. The top and bottom skin of the table is 0.188-inch thick stainless steel with a pattern of 1/4-20 tapped holes on 1-inch centers. This helps vent the table, but the holes do not connect with every honeycomb cell so that some cells might buckle. The table manufacturer (Newport Research Corporation) recommends an upper limit of 1 psi/minute pressure change on compression or decompression. It should be noted that even if several cells are buckled or even destroyed, the basic structural integrity of the table should still be sound. Some mirror realignment of the optics might be required if the table top should bow.

Operating at reduced pressure has an effect on cooling of the lamp which will be discussed in the next section.

2.2 Temperature Effects

The specified operational temperature range is 0° to $30^\circ C$ (32° to $85^\circ F$). This temperature range will cause a change in focus of the collimator due primarily to a dimensional change in the table. The total path-length (focal length) of the collimator is 120-inches. The thermal growth for $\Delta T \approx 53^\circ$ can be computed as follows:

$$\Delta l = l\alpha\Delta T \qquad \text{where } l \approx \text{pathlength}$$

$$\alpha = \text{coeff. of expansion} \approx 6.5\times10^{-6}/^\circ F \text{ for stainless steel}$$

$$\Delta T = \text{temperature change}$$

$$\Delta l = (120'')(6.5\times10^{-6}/^\circ F)(53^\circ F)$$
$$= 0.041 \text{ inches}$$

Restating this, if the focus shift is not to exceed $\pm$ 0.001 inch from an infinity setting made at, say, $72^\circ F$ then

$$\Delta T = \pm \Delta l/l\alpha$$
$$= 0.001/(120)(6.5\times10^{-6})$$
$$= \pm 1.3^\circ F$$

As pointed out in the design review, a collimator focus error considerably in excess of $\pm$ 0.001 can be tolerated for almost any camera system likely to be tested. The reduction ratio $R = f_{COLLIMATOR}/f_{CAMERA}$.

The longitudinal focus shift in the camera is

$\Delta f_{CAMERA} = \Delta f_{COLLIMATOR}/R^2$

Therefore, for a 48-inch focal length camera, $R = 120/48 = 2.5$ and $R^2 = 6.25$. The limiting aperture of the collimator is 12-inches so the fastest relative aperture of a 48-inch camera is f/4. Using the Rayleigh criterion for depth of focus of a "perfect" (diffraction limited) lens

$$\begin{aligned} \Delta f &= 4\lambda(f\text{-no})^2 \\ &= 4(.55)(16) \qquad \text{assuming } \lambda = 0.55\mu m \\ &= 35.2\mu m = 0.0014'' \text{ or } \pm 0.0007'' \end{aligned}$$

No observable focus shift could therefore be detected theoretically if the collimator were defocused by

$$\begin{aligned} \Delta f &= \pm (0.0007'')(6.25) \\ &= \pm 0.004 \text{ inches} \end{aligned}$$

Using this figure for tolerable collimator focal setting,

$$\Delta T = \pm 5.2^{\circ}F \quad \text{from the nominal } 72^{\circ}F$$

infinity settin. In practice, the tolerable focal shift of the collimator, and therefore the allowable temperature range, will tend to be even greater than this.

In the case of a shorter focal length camera, the tolerable amount of collimator defocus increases rapidly. For example, using a 24-inch camera $R^2 = 25$

which menas that the collimator could be defocused by $\pm$ 0.025 inches and the camera would see a change of only $\pm$ 0.001. An 18-inch camera has $R^2 = 44.45$. If the table changed dimensionally 0.041 inches, which is the upper limit for the entire operational temperature range, any camera with a focal length of 18-inches or less would not undergo a change in focus greater than 0.001 inch.

Both the parabola and the beamsplitter are made of low expansion materials. The parabola is Cervit and the beamsplitter is Schlieren grade fused silica so no perceptable focus shift is anticipated due to dimensional changes of either.

Reduced atmospheric pressure causes an increase in lamp temperature to the extent that certain precautions must be taken. First of all, solder connections at the lamp socket are not used because of the high temperatures. Instead, brass tubes with set screws are used to connect the wires with the pins in the lamp base. Several thermal tests were made with a lamp and illumination system similar to that used in PETS. At a distance of about 1-inch from the aperture gate, approximately where the shutter goes, temperatures at one atmosphere ranged from about 121°F after five minutes to 134°F after

30 minutes. At 1 psi, these values ranged from $210^{\circ}F$ after five minutes to $257^{\circ}F$ after 30 minutes. No damage was done to the optics or filters. The shutter, according to the manufacturer (Vincent Associates) should be able to withstand temperatures well in excess of $200^{\circ}F$. The back of the stainless steel shutter blades is shiney to help reflect some of the thermal energy. As a general precaution, it is recommended that the lamp not be operated for more than approximately five minutes at 1 psi.

APPENDIX C

RECOMMENDED SPARES LIST

The recommended spares list for PETS is as follows:

- DKP lamp
- 3AG fuse, 10 amp, Slo-Blow
- MDL 0.25 fuse, 1/4 amp